METHODS AND SYSTEMS FOR DETECTING ICING CONDITIONS

TECHNICAL FIELD

[0001] The present invention is directed generally toward methods and systems for detecting icing conditions, for example, during aircraft flight.

BACKGROUND

[0002] Many modern aircraft, including commercial aircraft, general aviation aircraft, business aircraft and military aircraft are designed to fly through almost all types of weather. One potentially harmful weather condition that such aircraft encounter is in-flight icing. When flying through icing conditions, aircraft encounter regions of supercooled water droplets, which can impinge on critical aircraft surfaces (including wing leading edges, engine inlets and flight control surfaces), then freeze and form accretions of ice. The ice accretions can inhibit aircraft performance and/or damage the aircraft (e.g., by breaking off and striking aircraft components).

[0003] One approach to addressing aircraft icing is to provide the aircraft with in-flight anti-icing or de-icing equipment. Another approach, which can be used in conjunction with such equipment, is to provide the aircraft with an on-board ice detection system. Such detection systems can (a) trigger the anti-icing/de-icing equipment, and (b) alert the pilot to the presence of icing conditions so that the pilot can minimize the time spent in such conditions. One typical ice detection system is a magneto-resistive system, which detects ice as it accretes. One potential drawback with this system is that, because the ice must accrete before the icing condition is detected, the aircraft performance may degrade prior to

activating an anti- or de-icing system, or before flying out of the icing environment. Such a degradation, while not presenting a safety issue for the aircraft, can reduce fuel efficiency of the aircraft and therefore increase the cost of operating the aircraft.

SUMMARY

[0004] The present invention is directed generally toward systems and methods for detecting icing or incipient icing conditions external to a vehicle, for example, an aircraft. A system in accordance with one aspect of the invention includes a temperature sensor configured to direct a first signal corresponding to a temperature of an airstream. The system can further include a water content sensor configured to direct a second signal corresponding to a water content of the airstream. A processing unit can be coupled to the temperature sensor and the water content sensor to receive the first and second signals and, based on at least the first and second signals, provide an indication when at least the first and second signals taken together correspond to an at least incipient icing condition.

[0005] In further particular aspects of the invention, the water content sensor can include at least one of a liquid water content sensor, a total water content sensor, and an ice crystal sensor. The temperature sensor, the water content sensor, and the processing unit can be configured to mount to an aircraft, and the temperature sensor and the water content sensor can be positioned remotely from each other or in a single housing.

[0006] A method in accordance with another aspect of the invention includes receiving a first signal corresponding to a temperature of an airstream external to a vehicle, receiving a second signal corresponding to a water content of the airstream, and, based on at least the first and second signals, automatically generating an indication when at least the first and second signals taken together correspond to an at least incipient icing condition. In further particular aspects of the invention, the method can further include determining when the temperature sensor detects a temperature corresponding to a static temperature at or below a

local freezing point for water, determining when the water content sensor detects liquid water, and generating an indication only when both the temperature sensor detects a temperature corresponding to a static temperature at or below a local freezing point for water, and the water content sensor detects liquid water. In still a further aspect of the invention, the method can include receiving a third signal corresponding to a pressure of the airstream and determining whether the first signal corresponds to a temperature at or below which water freezes based on the first signal and the third signal together.

BRIEF DESCRIPTION OF THE DRAWINGS

[0007] Figure 1 is a partially schematic, isometric illustration of an aircraft having an ice detection system configured in accordance with an embodiment of the invention.

[0008] Figure 2 is a partially schematic, isometric illustration of components of an ice detection system configured in accordance with an embodiment of the invention.

[0009] Figure 3 is a flow chart illustrating a method for detecting at least incipient icing conditions in accordance with an embodiment of the invention.

[0010] Figures 4A-4B are flow diagrams illustrating aspects of methods for detecting at least incipient icing conditions in accordance with further embodiments of the invention.

[0011] Figure 5 is a partially schematic, cross-sectional illustration of an ice detection system having a water content detector and a temperature sensor co-located in accordance with an embodiment of the invention.

DETAILED DESCRIPTION

[0012] The present disclosure describes methods and systems for detecting icing or incipient icing conditions, for example, on board an airborne aircraft. Many specific details of certain embodiments of the invention are set forth in the following description and in Figures 1-5 to provide a thorough understanding of

these embodiments. One skilled in the art, however, will understand that the present invention may have additional embodiments, and that the invention may be practiced without several of the details described below.

[0013] Figure 1 is a partially schematic, isometric illustration of an aircraft 100 carrying an ice detection system 110 configured in accordance with an embodiment of the invention. In one aspect of this embodiment, the aircraft 100 includes a fuselage 104, wings 101 depending from the fuselage 104, and an empennage 103 positioned to provide stability and control about the aircraft pitch and yaw axes. The aircraft 100 can further include a propulsion system 102, for example, a twin engine arrangement, with each engine positioned in a podded nacelle depending from a corresponding wing 101. In other embodiments, the aircraft 100 can have other general arrangements.

[0014] In any of the foregoing embodiments, the ice detection system 110 can include a temperature sensor 120 and a water content sensor 130, each coupled to a processing unit 140 with a link 160 (shown as input links 160a, 160b). The processing unit 140 can be configured to receive data from the temperature sensor 120 and the water content sensor 130 and, based on the information received from these sensors, determine when icing or incipient icing conditions exist in the environment external to the aircraft 100. When such conditions exist, the processing unit 140 can automatically generate an indication signal, transmitted via an output link 160c to an indicator 150. In one aspect of this embodiment, the indicator 150 can provide information exclusively to personnel in the flight deck of the aircraft. In other embodiments, such information can also be provided to ground-based equipment and/or recording equipment carried by the aircraft 100. Further details of embodiments of the ice detection system 110 are described below with reference to Figures 2-5B.

[0015] Figure 2 is a partially schematic, isometric illustration of an embodiment of the ice detection system 110. In one aspect of this embodiment, the temperature sensor 120 and the water content sensor 130 are positioned remotely from each other and mounted to the aircraft 100 (external surface portions of which are

shown in Figure 2). In another embodiment, described in greater detail below with reference to Figure 5, the temperature sensor 120 and the water content sensor 130 can be co-located in a single device. In either embodiment, the temperature sensor 120 and the water content sensor 130 are operatively coupled to the processing unit 140 to provide the information necessary for the processing unit 140 to determine when at least incipient icing conditions exist. As used herein, the term at least incipient icing conditions is used to include conditions generally favorable to the formation of ice, and/or conditions under which ice is actually forming.

[0016] In one aspect of an embodiment shown in Figure 2, the temperature sensor 120 can include a static air temperature probe that directly measures the static temperature of the airstream external to the aircraft 100. In another embodiment, the temperature sensor 120 can include a total temperature sensor, such as a model 300536 TAT sensor, from SpaceAge control of Palmdale, California. Because the determination for incipient icing conditions is typically based on the static air temperature, if the temperature sensor 120 includes a total air temperature probe, the system 110 can further include a pressure sensor 170 that provides data by which the processing unit 140 can determine the static air temperature based on the total air temperature. In one aspect of this embodiment, the pressure sensor 170 can include the pitot-static probe system typically provided on the aircraft 100. In other embodiments, the pressure sensor 170 can include other separate systems. In any of these embodiments, the pressure sensor 170 can detect the total air pressure and static air pressure of the environment outside the aircraft 100 and transmit corresponding signals to the processing unit 140 via input links 160d and 160e. Based on this information, the processing unit 140 can calculate the static air temperature and combine this information with information received from the water content sensor 130 to determine incipient icing conditions. In another embodiment, a separate device can calculate the static air temperature from the pressure data. Such devices are available from Insight Avionics of Buffalo, New York.

[0017] In one aspect of an embodiment shown in Figure 2, the water content sensor 130 can include a liquid water content measuring probe, such as a Johnson-Williams probe, available from Particle Measuring Systems, Inc. of Boulder, Colorado. Such a probe can determine the liquid water content of the airstream passing through it based on heat loss from a heated wire which is positioned to be impinged by water in the airstream. In other embodiments, the water content sensor 130 can have other arrangements. For example, the water content sensor 130 can include an ice crystal sensing capability and/or a total water sensing capability to detect mixed-phase or ice crystal icing conditions. In a particular aspect of this embodiment, the ice crystal sensing capability and/or the total water sensing capability can be provided in addition to the liquid water sensing capability. In any of these embodiments, the water content sensor 130 can generate a signal, transmitted via the input link 160a, which can indicate whether or not the airstream passing adjacent to the aircraft 100 includes water.

[0018] In any of the foregoing embodiments, the processing unit 140 can receive information from the temperature sensor 120, the water content sensor 130 (and, optionally, the pressure sensor 170). The processing unit 140 can include an existing portion of the aircraft flight data system (e.g., programmed to carry out the above functions), or a stand-alone unit, either of which can provide an output signal to the output indicator 150 via the output link 160c. In one embodiment, the output indicator 150 can include a visual display positioned for visual access by the flight crew, so that the flight crew can be made aware of incipient icing conditions and can respond accordingly, for example, by changing the aircraft flight path and/or by activating an anti-icing or de-icing system. In other embodiments, the output indicator 150 can include an audible alarm or can provide notification to the flight crew via other techniques. In any of these embodiments, the processing unit 140 can collect and process data to provide the appropriate output signal, as described in greater detail below with reference to Figures 3-4B.

[0019] Figure 3 is a flow chart illustrating a method 300 (carried out, for example, by the processing unit 140) for determining at least incipient icing conditions in accordance with an embodiment of the invention. In one aspect of this embodiment, the method 300 can include determining a static air temperature of an airstream (process portion 302) and determining a liquid water content of the airstream (process portion 304). The method 300 can further include determining whether the static air temperature is at or below a pre-selected threshold value (process portion 306). In one aspect of this embodiment, the pre-selected threshold value can be fixed for all flight conditions, and in other embodiments, the threshold value can depend on certain flight conditions, for example, aircraft altitude. In either embodiment, if the static air temperature is not at or below the threshold value, the method includes not indicating an icing condition (process portion 308). If the static air temperature is at or below the threshold value, the method 300 proceeds to process portion 310.

[0020] In process portion 310 the method 300 includes determining whether the liquid water content is at or above a threshold value. In a particular aspect of this embodiment, the threshold value can be non-zero, so that the system does not provide positive indications for inconsequential amounts of detected liquid water content. If the liquid water content is not at or above the threshold value, the method 300 includes not indicating an icing condition (process portion 308). If the liquid water content is at or above the threshold value, then the method 300 can include indicating at least incipient icing conditions (process portion 312).

[0021] Figures 4A-4B illustrate further details of process portions 302 and 306, in accordance with other embodiments of the invention. Referring first to Figure 4A, process portion 302 (which includes determining the static air temperature of the airstream) can include first receiving a signal corresponding to a total air temperature (process portion 402), for example, from a total air temperature probe. The method can further include receiving signals corresponding to a total air pressure (process portion 404) and static air pressure (process portion 406), for example, from a pressure sensor 170 (described above with reference to

Figure 2). In process portion 408 the static air temperature is calculated, for example, using readily available techniques based on the total air temperature and the ratio of the static air pressure to the total air pressure. In other embodiments, the static air temperature can be calculated in accordance with other methods. For example, the static air temperature can be calculated based on the received total air temperature signal (process portion 402) and an indication of the speed and altitude of the aircraft, which may in turn be based upon calculations from the total air pressure and static air pressure signals described above. In any of these embodiments, process portion 302 can include either determining the static air temperature of the airstream directly from a static air temperature sensor, or indirectly via calculations performed on data received from a total air temperature sensor.

[0022] Referring now to Figure 4B, process portion 306 (which includes determining whether the static air temperature is at or below a threshold value) can include receiving the static air temperature value (process portion 420) and receiving signals corresponding to the total air pressure (process portion 422) and static air pressure (process portion 424). The method can further include calculating the pressure-altitude at which the aircraft is flying (process portion 426). Based on the total air pressure and the static air pressure, the method can further include calculating a local freezing point, based on the pressure altitude (process portion 428). In process portion 430, the method can include comparing the local freezing point to the static air temperature value to determine whether the static air temperature value is at or below the local freezing point. If so, then the method includes determining whether the liquid water content is at or below the threshold value (process portion 310, discussed above with reference to Figure 3). If not, then the method includes not indicating an incipient icing condition (process portion 308, Figure 3).

[0023] In any of the embodiments described above, the foregoing methods can be completed by a suitable computing system, including the aircraft flight data system or a separate system. The routines for carrying out the processes

described above can be encoded in hardware, software or other computer-readable media. In any of these embodiments, some or all of the foregoing processes are completed automatically. An advantage of this arrangement is that it can reduce crew workload and improve system repeatability and reliability.

[0024] In one aspect of an embodiment described above with reference to Figure 2, the ice detection system 110 includes a temperature sensor 120 positioned remotely from a water content sensor 130. In another embodiment, shown in Figure 5, an ice detection system 510 can include a temperature sensor 520 and a water content sensor 530 co-located in a single housing 511. In one aspect of this embodiment, the housing 511 can include a base 514, a support 515 extending away from the base 514, and a flow channel 512 carried by the support 515. The flow channel 512 can include an entrance 516 and an exit 517 positioned downstream from the entrance 516 and aligned with the entrance 516 along a flow axis 513. The flow channel 512 can carry a probe mast 531 extending into the airstream captured by the flow channel 512. The probe mast 531 can support a heated wire 532 which is positioned to impinge water (for example, liquid water) contained in the captured airstream. In a particular aspect of this embodiment, the temperature sensor 520 can be positioned at a lee surface of the probe mast 531, so as not to be directly exposed to water in the captured airstream. Accordingly, the temperature sensor 520 can measure the actual total or static temperature without being influenced by any water in the captured airstream. The detector 510 can optionally include a pre-processor 541 (for example, to condition the signals received from the heated wire 532 and the temperature sensor 520) and can provide output signals to a processing unit (such as the processing unit 140 described above) via output links 560a and 560b.

[0025] One feature of at least several of the embodiments of the systems described above is that they can automatically determine at least incipient icing conditions based on signals corresponding to both temperature and water content. As discussed above, this arrangement can reduce crew workload and

improve system performance. Another feature of at least several embodiments of the systems described above is that they can detect conditions favorable for ice formation without first requiring significant accretions of ice to form. As a result, the flight crew can more quickly respond to the presence of icing conditions, for example by changing flight path and/or activating an ice protection system.

[0026] From the foregoing, it will be appreciated that specific embodiments of the invention have been described herein for purposes of illustration, but that various modifications may be made without deviating from the spirit and scope of the invention. Accordingly, the invention is not limited except as by the appended claims.